# Channel Models for the Simulation of Different RATs Applied to Platoon Emergency Braking

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***Abstract*—We analyze the performance of different channel models and Radio Access Technologies (RATs) for platoon emergency braking in a highway scenario. We present a ray tracing channel model and analyze its differences with the WINNER+ stochastic channel model in terms of the pathloss calculation. Thanks to the consideration of obstacles and their reflections, the ray tracing channel model has been shown to be more realistic in near Tx-Rx distance. This corroborates the results of our performance comparison which highlights larger differences in close Tx-Rx pairs. Considering the simulation time consumption and the more realistic ray tracing predictions, we propose a new models usage for our simulations: a combination of WINNER+ and ray tracing channel models. Moreover, we implement one new 5G numerology on the basis of Long Term Evolution-Vehicles (LTE-V) for Vehicle-to-everything (V2X) communications. We include this new feature in our benchmarking setup and provide performance analysis results. It provides a basis for our future research of further 5G components.**

## I. Introduction

Road safety is a key feature of Vehicle-to-everything (V2X) communications, an important part of Intelligent Transportation Systems (ITS). In the future, it is aimed to share basic information as well as emergency warning signals between vehicles through the exchange of regular messages. These messages include Cooperative Awareness Messages (CAMs) [1] and Decentralized Environmental Notification Messages (DENMs) [2], as standardized for the European ITS-G5 system [3].

Several Radio Access Technologies (RATs) are proposed to support the V2X communications. In this scope, IEEE provides the 802.11p standard; it offers *ad-hoc* communication links and a dedicated band at 5.9 GHz for the ITS users [4]. Although IEEE 802.11p is the main standard for V2X communications, it can be challenged by high densities of users when transmitting multiple types of messages such as CAM and DENM, as well as other messages that are currently in standardization. Indeed, this multiplicity of messages pushes decentralized congestion control to its performance limits [5], [6]. The cellular technology Long Term Evolution (LTE) is emerging as new alternative for V2X communications. In [7], 3GPP specifies the features for V2X, with two specific modes, the so-called modes 3 and 4. In the former, resources are allocated by an LTE Base Station (BS). In the latter, resources are assigned without the help of the cellular network, but by random access and semi-persistent scheduling. Recently, the next generation of cellular communications technology, 5G, became a new concept in V2X communications; it is expected to improve the performances in terms of higher reliability and lower latency for instance [8].

We focus on a scenario in which a platooning system composed by heavy-duty trucks is driving in an environment comprising high density of communicating road users. This scenario is an interesting and challenging application of V2X communications. Indeed, the platooning system is supported by V2X while the wireless channels may be loaded by the surrounding traffic. In order to target smaller latency and higher reliability, RATs should be carefully selected. In [9], we analyzed the performances of IEEE 802.11p as well as LTE-V for a platoon emergency braking use case in a high density highway scenario. In this previous work, we restricted our analyses to performance resulting from a stochastic channel model. In this paper, we introduce ray tracing predictions and analyze the influence of channel models. We assess the technologies with Key Performance Indicators (KPIs) such as delay and Packet Error Rate (PER). Furthermore, we implement a new numerology for 5G which gives the potential for further development.

For our simulations, we use the Simulator for Mobile Networks (SiMoNe) [10]. It is a system level simulator written in C#, developed by the Institute for Communications Technology at TU Braunschweig. It has the ability to work with realistic urban and rural scenarios, 3D pathloss predictions, time-varying subscriber distributions as well as multi-technology networks. Because our platoon emergency braking maneuver includes the reaction to event triggered messages, it is necessary to have an online data connection between SiMoNe and the traffic simulator Simulation of Urban Mobility (SUMO) [11]. This connection allows to use mobility data to update SiMoNe on the one hand, and the control commands to SUMO on the other hand, allowing the control of V2X equipped vehicles. This coupling between the two simulators is operated using Traffic Control Interface (TraCI).

The remaining of this paper is structured as follows: In Secs. II and III, we illustrate the theory behind our channel models and communication technologies respectively. Then, we explain the simulation scenarios and settings in Sec. IV. After that, the simulation results and our evaluations are given in Sec. V. Finally, we conclude this paper with the main findings.

This work has been supported in part by the Federal Ministry of Education and Research of the Federal Republic of Germany (BMBF) in the framework of the project 5G NetMobil with funding number 16KIS0681. The authors alone are responsible for the content of the paper.

https://doi.org/10.24355/dbbs.084-201905081042-0

## II. V2X Channel Models

The physical channel modeling is essential for the determination of transmission properties and the calculation of interference. We introduce the stochastic and ray tracing channel models in this section.

### A. WINNER+ Model

The stochastic WINNER+ channel model [12] uses clusters of reflecting objects to model small scale fading for several propagation scenarios. The large scale fading is firstly predicted: it is mainly determined by dichotomizing the links between Line-of-Sight (LOS) and Non Line-of-Sight (NLOS). Then, the individual cluster parameters are determined, such as the arrival and departure angles. Although the WINNER+ model has been modified for Device-to-Device (D2D) within 3GPP, it is only realistic if one transceiver is static [13].

### B. Ray Tracing Model

The main feature of ray tracing is the ray calculation. The ray tracing model implementation in SiMoNe simulates each link simultaneously. For each communication link, the rays are first calculated on the direct path; these rays can be free space propagated rays or transmitted rays depending on whether there are obstacles in the direct path. Then, the reflection and diffraction paths are determined by the Image-Source-Tree.

Computing time is an important factor for the channel modeling. Though calculating the rays with high order interactions gives the ray tracing high accuracy, it however leads to high computing time, which limits the practical use of the ray tracing for modeling a scenario with large number of subscribers [14]. To cope with this limiting factor, we limit the maximum communication range of the communication links and filter the considered building data using a bounding box.

In order to further accelerate the ray tracing predictions, we simplify the settings in the following way:

- Ignoring influences from the surrounding buildings;
- Ignoring transmissions and diffractions from vehicles;
- Maximum reflection order from the vehicles of 1;
- Maximum ray tracing range of $1000\,\mathrm{m}$.

The calculation time decreases dramatically by applying the above settings. However, ray calculation time is still a challenge for SiMoNe. We will describe further attempts to decrease the calculation time in the following.

## III. Communication Technologies

In this paper, the V2X communications use three RATs: IEEE 802.11p, LTE-V and 5G. The implementation of IEEE 802.11p and LTE-V are described in details in our previous work [9].

### A. IEEE 802.11p

For 802.11p, we use G5-CCH—a $10\,\mathrm{MHz}$ band in the $5.9\,\mathrm{GHz}$ frequency region—which is used in the European Union for road safety [15]. Messages between users are sent using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) channel access method [16]. The core idea behind CSMA/CA is Listen Before Talk (LBT): a vehicle measures the received energy on its Rx interface and compares it with predefined threshold. The vehicle assumes the channel to be free and immediately starts transmitting if the measured value is smaller. Otherwise, the channel is considered occupied, either by the reception of packets or by other on-going communications. A back-off process is subsequently initiated by deferring the access time by a random back-off time to avoid collisions.

In our simulations, the messages are broadcast to all vehicles with a transmission speed of $6\,\mathrm{Mbit/s}$. We simplify the packet reception by omitting the modeling of channel coding and decoding. A message is assumed to be correctly received if the Signal to Interference plus Noise Ratio (SINR) exceeds the predefined SINR threshold value of $10\,\mathrm{dB}$ [17].

### B. LTE-V

We restrict our scope to LTE-V mode 4 in order to focus on standalone technologies, for which we have to make less assumptions. Communications are operated through the PC5 interface using a frequency of $3.4\,\mathrm{GHz}$ and a signal bandwidth of $10\,\mathrm{MHz}$. The resource allocation is performed without the help of BS, but based on Sensing-Based Semi-Persistent Scheduling (SBSPS) [18]. Subscribers are assumed to find their Sidelink Control Information (SCIs) within $20\,\mathrm{ms}$. As for 802.11p, a $10\,\mathrm{dB}$ SINR threshold value is defined for transmission evaluation.

### C. 5G

The air interface defined by 3GPP for 5G is subdivided into two frequency bands: FR1 for frequencies below $6\,\mathrm{GHz}$; and FR2 for mmWaves, located in higher bandwidths [19]. We focus on the FR1 frequencies.

The main aspects of 5G for V2X communications are new numerologies and a new frame structure. In LTE, the subcarrier spacing is fixed to $15\,\mathrm{kHz}$, which includes $7$ Orthogonal Frequency Division Multiplexing (OFDM) symbols. For the frame structure in 5G, the length of slot also scales with the subcarrier space, but with $14$ OFDM symbols [20]. For communications in a band below $6\,\mathrm{GHz}$, the subcarrier space of $15\,\mathrm{kHz}$, $30\,\mathrm{kHz}$ and $60\,\mathrm{kHz}$ are suggested [21]. We do not implement the $60\,\mathrm{kHz}$ subcarrier spacing as it was not included in this frequency band at the time this work was commenced. It is however subject to our future work.

Similarly to the non-cellular mode of LTE-V, we also focus on the non-cellular mode for 5G. More precisely, for LTE-V, there are $50$ Physical Resource Blocks (PRBs) in $10\,\mathrm{MHz}$ band within a subframe ($12$ subcarriers $\times$ $14$ OFDM symbols, $90\,\%$ bandwidth utilization). For 5G numerology 1, we have two slots per subframe and $30\,\mathrm{kHz}$ subcarrier spacing. Therefore, we have $55$ PRBs because of the higher bandwidth utilization ratio ($0.98$ for 5G and $0.9$ for LTE-V).

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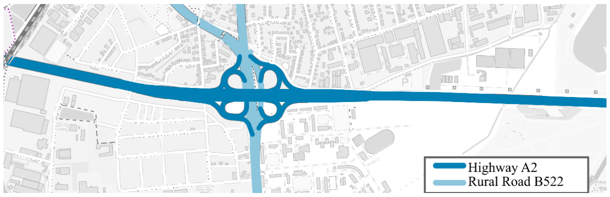


Fig. 1. Highway scenario in Open Street Map.

## IV. Simulation Settings

In this section, the simulation settings are described, including the simulation scenario and the application use case.

### A. Simulation Scenario

The truck platoon drives within the vehicular traffic on a model of a real-world scenario. The road network is generated by SUMO based on Open Street Map (OSM) data. We choose part of Highway A2 in the north of Hannover (see Fig. 1), the whole length of the road is about $3650\,\mathrm{m}$ with three lanes in each direction.

The vehicles routes are generated based on the aforementioned network under the form of an XML route file. This route file contains the vehicle parameters, such as car length, route ID, vehicle ID, maximum speed and maximum acceleration. The vehicles will then be randomly distributed on these routes. For the vehicular traffic generation, two types of vehicles are considered: trucks for platoon members and normal passenger cars for the surrounding traffic. The main parameters of these two models are given in Tab. I. Later, by interaction with the control system, the car following model and the parameters such as acceleration and deceleration are overridden by the control from SiMoNe through TraCI.

In [9], we were varying the number of trucks and the inter-vehicle distance in the platoon. In the present paper, we choose the most challenging case, which is $11$ trucks with $5\,\mathrm{m}$ inter-vehicle distance. Besides these parameters, the density of surrounding traffic is also an important value in the simulation as it can influence the channel load as well as the link quality between vehicles. To study the influence of this vehicular traffic density on the communications, we add this traffic with increasing densities.

### B. Use Case

We analyze the performance of communications in a platoon emergency braking use case. Three types of messages are defined for the use case:

- Cooperative Awareness Message (CAM): CAM is standardized in ITS-G5 for car-to-car communications, it contains the current status of the vehicles; each vehicle periodically broadcasts the $400\,\mathrm{B}$ CAM with a generation rate of $1\,\mathrm{Hz}$–$10\,\mathrm{Hz}$;
- Platoon Control Message (PCM): PCM is a periodic message sent by platoon members with a packet size of $700\,\mathrm{B}$ and a generation rate of $20\,\mathrm{Hz}$;
- Emergency Message (EM): EM is an event triggered message which contains a warning that will launch the emergency maneuver. After the emergency case is triggered, it is periodically broadcast with a packet size of $700\,\mathrm{B}$ and a generation rate of $20\,\mathrm{Hz}$.

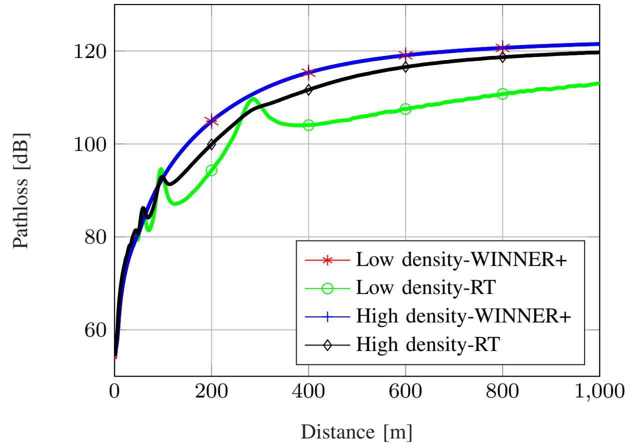


Fig. 2. Pathloss of WINNER+ and ray tracing channel models with different traffic densities as a function of distance.

In our application, all the vehicles communicate with each other with the periodic CAMs. Besides this, each platoon member adapts the inter-vehicle distance with the forward member with the help of PCMs. At a specific timestep, an emergency maneuver is detected by the first platoon member. Then, it triggers its own emergency braking and sends EMs to all other members. The emergency braking of other platoon members is executed after receiving the EMs.

TABLE I. Vehicle parameters in SUMO

| Type | `truck` | `passenger car` |
|---|---|---|
| Car following model | `IDM` | `Krauss` |
| Max. speed | $80\,\mathrm{km/h}$ | $160\,\mathrm{km/h}$ |
| Target velocity | $72\,\mathrm{km/h}$ | $\mathcal{N}(120,\,0.3)\ \mathrm{km/h}$ |
| Max. acceleration | $1.5\,\mathrm{m/s^2}$ | $2.9\,\mathrm{m/s^2}$ |
| Max. deceleration | $-3\,\mathrm{m/s^2}$ | $-7.5\,\mathrm{m/s^2}$ |

## V. Results and Evaluations

In this section, we show our simulation results and evaluate them. Firstly, we analyze the results from the analyses of the influence of the different channel models, then we show the results of the RATs performance comparison using the ray tracing channel model.

### A. Results for Channel Models

We compare the WINNER+ and ray tracing channel models in this first results part. We spawn normal passenger cars in the simulation with two densities: $1500\,\mathrm{vehicles/h}$ and $6000\,\mathrm{vehicles/h}$. All the vehicles broadcast solely CAMs; no other types of messages and applications are considered. For both traffic densities, we run the simulations using the stochastic WINNER+ and the realistic 3D ray tracing models. For each model, we can gather thousands of Tx-Rx pairs. We then evaluate KPIs such as pathloss and ratio of correctly received messages as a function of distances up to $1000\,\mathrm{m}$. We show the mean value over $30$ randomized simulations with pathloss prediction updated every $100\,\mathrm{ms}$.

https://doi.org/10.24355/dbbs.084-201905081042-0

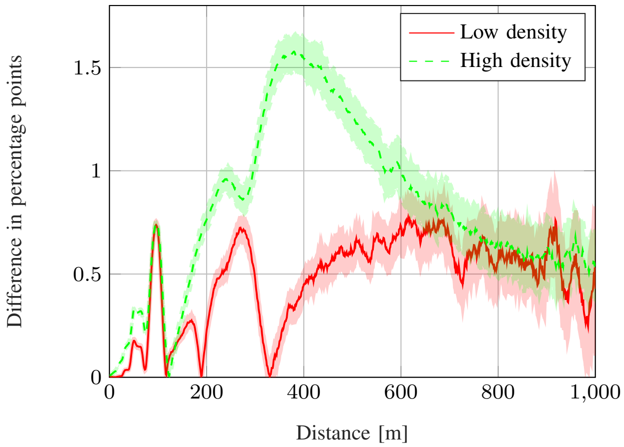


Fig. 3. Difference of correctly received messages in percentage points between WINNER+ and ray tracing channel models as a function of distance. The light areas correspond to the 95% confidence intervals.

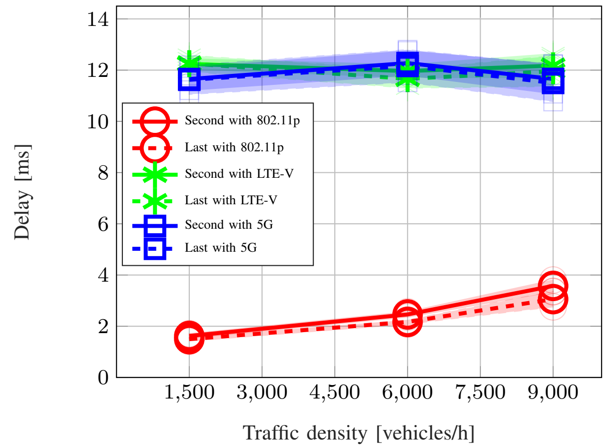


Fig. 4. Average delay for the second (solid line) and last (dashed line) platoon members as a function of the traffic density by using IEEE 802.11p (red circle), LTE-V (green star) and 5G (blue square). The light areas correspond to the 95% confidence intervals.

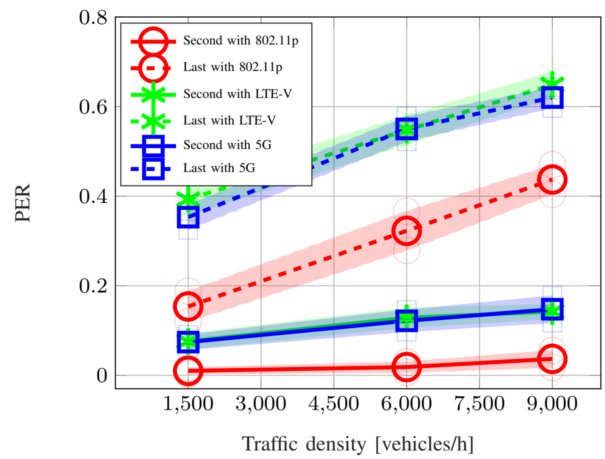


Fig. 5. Average PER for the second (solid line) and last (dashed line) platoon members as a function of the traffic density by using IEEE 802.11p (red circle), LTE-V (green star) and 5G (blue square). The light areas correspond to the 95% confidence intervals.

Fig. 2 shows the relationship between pathloss and the transmitter-receiver distance for different scenarios: WINNER+ and ray tracing channel models with low and high traffic densities. It can be observed from the figure that the traffic density has no influence on the pathloss of the WINNER+ model (superimposed red and blue curves), because only the parameters such as Tx-Rx distance and frequency band determine the pathloss of WINNER+ model. For the ray tracing model, the pathloss is higher with high density as more obstacles are considered. Moreover, we can find that the difference in pathloss between ray tracing and WINNER+ models is fluctuating for near Tx-Rx distances, and steadier for large distances. We investigate the ratio of correctly received messages, which is essential for the platoon emergency braking use case. We show the difference between these two channel models in percentage points in Fig. 3 for the 802.11p RAT. Similarly to the pathloss results, the difference between the two channel models is fluctuating for near Tx-Rx distances and converges for large distances. Correctly receiving a message is indeed determined by the SINR in our simulations.

As a result, we conclude that the ray tracing model is more relevant for near distances. Indeed, between near Tx-Rx pairs, the obstacles can affect communications with less reflection possibilities and a higher LOS blockage. These effects are however not covered in the WINNER+ model. Considering the computation resources required to run the ray tracing model, this emphasizes the possibility to focus on ray tracing model for near distances and switch to WINNER+ model for larger distances.

In the following simulations, we further implement a *white list* for pathloss calculations: the ray tracing model is only used when one vehicle of the Tx-Rx pair is a platoon member. Otherwise, we use the WINNER+ channel model in order to accelerate the simulations.

### B. Results for Radio Access Technologies

In this second results part, we analyze the performance of our three RATs with the following KPIs:

**PER:** ratio between the number of not received messages and the total number of transmitted messages;

**Delay:** radio channel latency caused by signal processing and scheduling delay, it is an average over all transmissions during a timestep.

We present the simulation results with traffic densities of 1500, 6000 and 9000 vehicles/h. Besides the surrounding traffic in the highway, we also generate some traffic in the rural area near the highway. As described in Sec. IV, three types of messages are considered in the use case: CAMs, PCMs and EMs. Considering the requirement of frequent update for the event triggered messages, the simulator time resolution of information update and message transmission is 10 ms. In this safety-related time-critical use case, the performance of the communications system for the EM are of particular interest. Therefore, we analyze the delay (see Fig. 4) and PER (see Fig. 5) of EM during a period of 3 s after the emergency case is triggered.

https://doi.org/10.24355/dbbs.084-201905081042-0

For 802.11p, the delay is larger for the higher traffic density because of the higher message collision probability, although the values stay in a low range (under $5\,\mathrm{ms}$). For LTE-V and 5G with numerology $1$, considering that we assume that users have to find an SCI within $20\,\mathrm{ms}$, the delay is not larger with the growing traffic, but close to the same range ($10\,\mathrm{ms}$–$15\,\mathrm{ms}$). It should be noted that there is an inverse relationship between the delay and Tx-Rx distance: our delay is an average measured from the receiver, which means that the far receiver only receives messages in the best conditions.

As for the PER of all RATs, it suffers from higher interference levels in denser surrounding traffic, which leads to larger PER values. Furthermore, as expected, the last platoon member also experiences larger PER values than the second one. The received SINR determines whether a message is correctly received and SINR has an inverse relationship with pathloss. The last platoon member being farther from the transmitter, its pathloss value is higher. As a result, the SINR is lower and the PER higher.

Focusing on the performance analyses between LTE-V and 5G, the delay and PER are rather similar. This is explained by the similar implementations and settings, especially for the resource allocation of LTE-V and 5G numerology $1$. The implemented numerology, in this setup, has not a significant impact on the observed KPIs. However, the implementation of 5G with new numerologies provides a basis for our future research and development in SiMoNe, *e.g.* the analyses of more numerologies as well as the network slicing in 5G.

## VI. Conclusion

In this paper, we make further implementations and analyses on the basis of our previous work on benchmarking setup for RAT comparison.

To evaluate the difference between the ray tracing and WINNER+ models, we generate a simple highway scenario and analyze the influence of channel models by sending CAMs. We find that the ray tracing model presents clear differences with the WINNER+ model in the case of near Tx-Rx distances. Considering the requirements of calculation precision and speed, this result shows the possibility to use ray tracing model for near Tx-Rx pairs and WINNER+ model for far Tx-Rx pairs. In terms of the RATs, we evaluate the delay and PER in a platoon emergency braking use case. Three RATs are used for the V2X communications: IEEE 802.11p, LTE-V mode 4 as well as 5G with the new numerology. The surrounding traffic density and the distance between Tx-Rx are parameters influencing the KPIs.

In the future work, our target is to implement and analyze further numerologies as well as network slicing in 5G. Furthermore, in order to improve the efficiency and safety of the messages transmission, we intend to develop a traffic steering algorithm which can transmit messages by steering among different RATs.

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